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Heteropolar ferroelectrets for ultrathin flexible keyboards and tactile sensors

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Abstract

Ferroelectrets are flexible and conformable polymer transducer materials with a dominant longitudinal piezoelectric effect. They can be used in a wide range of transient pressure sensing applications. We present concepts for thin, flexible ferroelectret-keyboards (and advanced pressure sensors) based on ternary coded polarization patterns in a multilayer configuration. The decoration of a cellular polypropylene ferroelectret with a heteropolar polarization pattern of high resolution is a technical challenge. We discuss several concepts for achieving such polarization patterns and demonstrate a flexible 300 μm thin 3-layer keyboard where the combined signals of every single layer allow to encode and detect a total number of 26 keys.

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Key words: ferroelectrets, corona charging, contact charging, flexible electronics, large scale

1. Introduction

Rollable ultra-thin, sheet-type keyboards and tactile sensors may trigger a wealth of applications in flexible electronics. Such lightweight and non-breakable electronic peripheries may be successfully integrated in textiles and artificial skins. More conventional applications may also benefit from paper-thin interfaces, which may even be highly elastic and conformable. A promising concept for an efficient, yet simple and thus low cost fabrication of a thin, flexible keyboard is based on the electroactive cellular polypropylene ferroelectret (CPPF). [1] This flexible polymer material, with a thickness of less than 80 μm , can be produced in large scale [2] and shows a strong piezoelectric response upon compression along the 3-axis, with a corresponding piezoelectric coefficient of $d_{33} \sim 100 - 300 \text{ pC/N}$, but a negligible response when bending, due to the very small d_{31} and d_{32} piezoelectric coefficients [3] - a unique behavior among piezoelectric materials. This qualifies CPPF as almost ideally suited material for rollable and bendable keyboards and tactile sensors.

2. Experimental

The closed cell polypropylene foam acquires piezoelectricity due to corona or contact poling. At field strengths of about 100 MV/m a gas discharge within the cellular voids occurs, followed by charge separation and charge trapping, thereby polarizing the voids. [4, 5] These voids then act as macroscopic dipoles, and the material is thus rendered electroactive. The polarization in a single CPPF foil can be uniform over the entire layer or structured, with alternating regions of up and down polarization states. A layer patterned with regions of up and down polarization states is equivalent to a digital encoded surface which produces a positive or negative piezoelectric signal trace when actuated.

The different signals from one single layer allow for a unique identification of two individual regions. The number of identifiable regions is increased by combining several layers to a multilayer stack as shown in Fig. 1(a). The scheme

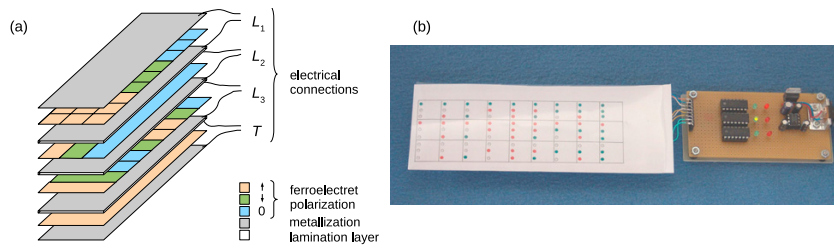


Figure 1: Schematic of a 3-layer ferroelectric keyboard (a). Three-layer ferroelectric keyboard prototype with electronic reading device (b).

shows a ternary coded 3-layer keyboard using the two polarization states, (+1 or -1) in combination with inactive states, (0), of unpoled or depolarized areas. The forth layer is uniformly polarized and serves as a trigger layer to detect also the inactive combination (0,0,0). A single event causes signals from every layer which are detected separately. All signals together are then interpreted as a combinatorial set. Without a trigger layer the number of different keys, k , scales with the number of layers, l , according to the combinatorial law $k = 3^l - 1 = \{2, 8, 26, 80, 242, \dots\}$. Most applications can be realized with less than four layers. Our experimental prototype in Fig. 1(b) is a simple demonstration of the 3+1 multilayer stack outlined in Fig. 1(a). Because of the piezoelectric nature of the CPPF the keypad does not need a power supply, but the signals are connected directly, without any preconditioning, to simple general purpose FET transistors (2 for each layer) which switch the state of a standard D-type flip flop.

Such a low level reading-circuitry works reliable only if the CPPF layers are sufficiently sensitive and the respective piezoelectric signals are strong enough. The strength and quality of the piezoelectric signal is directly related to the quality of the polarization which is crucially dependent on poling conditions. A fairly homogeneous polarization throughout an entire CPPF layer can be achieved both easily and effectively by means of a corona discharge. Figure 2 shows a schematic of the corona system used for polarization.

Unfortunately, this simple corona system is less effective for structured area polarization, and alternating regions with up and down polarization states are even more difficult to obtain. Polarization via a corona discharge is achieved by ionized molecules in the air which follow the potential difference, drifting away from the high voltage corona needles, down to the CPPF sample, where they charge up the surface to a high potential, sufficient for internal gas discharges in the voids of the CPPF. In principle, structured polarization can be obtained, if the ions charge up only pre-specified areas. Areas which should stay unpolarized may be covered by a shadow mask. The necessary requirements for a shadow mask however, are difficult to fulfill. The mask has to be fairly thin, in order to achieve a good edge-resolution. Also, the mask should possibly not affect the electric field and potential. Simultaneously, to avoid polarization reversal of already oppositely polarized areas, the mask should as well screen, to a large degree, the external field from such areas. An external poling field, E_c , with the minimum critical field strength for gas breakdown,

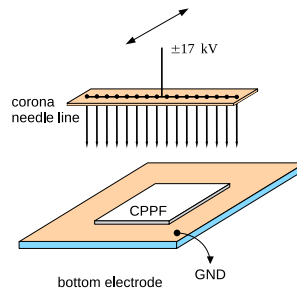


Figure 2: Corona setup, consisting of a planar ground electrode and a movable needle line, connected to high voltage potential.

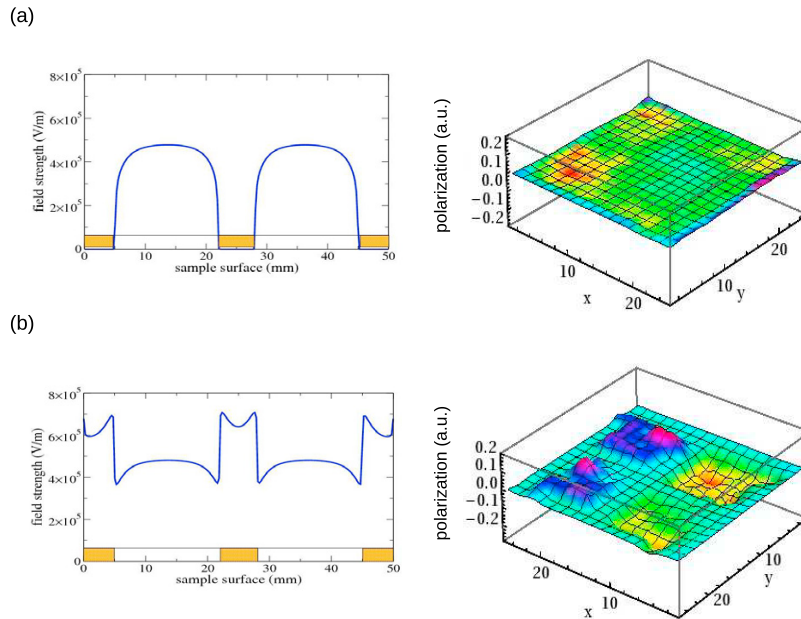


Figure 3: Initial electrostatic field strength across the surface of a shadow masked CPPF in a corona setup without ionic charges, for a grounded metal-mask (a, left) and a dielectric mask (b, left). Measured polarization of corona poled CPPF samples ($4 \times 4 \text{ cm}^2$), utilizing a grounded metal-mask (a, right), and a dielectric mask (b, right).

E_b , is necessary to cause a polarization, P , which reduces the internal field, $E_i \sim E_e - P < E_b$. A depolarization or polarization reversal now does not occur at $-E_e < -E_b$ but at much lower poling fields, $-E_e < P - E_b$. It is important therefore, that the already polarized areas are not exposed to the corona field of opposite polarity during the second step of polarization.

All together, these are contradicting requirements. A mask which does not affect the electric field requires a very low dielectric permittivity, but a mask which has to screen external fields require a high permittivity. The situation is illustrated with a finite element method (FEM) field analysis shown in Fig. 3(a) for a grounded metal mask and for a dielectric mask in Fig. 3(b). In the case of the grounded metal mask, the covered regions are perfectly shielded, but the strong potential gradient towards the metallic regions guide all ions away from the open regions which are not getting charged and therefore the sample is not getting polarized. An experimental measurement, where the CPPF is measured with an electromechanical test stage [6], is in agreement with the theoretical analysis, and virtually no polarization is being measured.

The FEM field analysis for a 1 mm thick dielectric shadow mask, in Fig. 3(b) shows a more favorable potential distribution, with a potential difference towards the open regions, but due to a slightly higher permittivity of $\epsilon=2.5$ compared to the low permittivity of $\epsilon=1.5$ for the polypropylene foam, already very strong edge-effects emerge, which cause an inhomogeneous polarization. Simultaneously, the permittivity of the mask is too low for a sufficient shielding of the corona field and at least a partial polarization reversal of oppositely polarized areas is inevitable.

A possible solution to the described problem is schematically depicted in Fig. 4(a). For each polarization we have used a separate dielectric shadow mask, a 1 mm thick polymer to prevent any unwanted surface charging, and a grounded electrode which matches up exactly with the open windows of the mask. With a corona voltage of about 17 kV, a needle-to-ground distance of 2.5 cm and a 20 cm long needle line with a needle-to-needle separation of 5 mm we were able to achieve an up and down polarization as shown in Fig. 4(b). Though, this method seems to

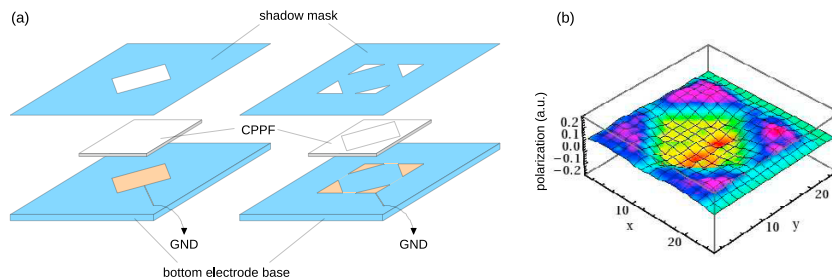


Figure 4: Individual shadow mask system for positive and negative corona polarization (a). Bipolar corona-polarized CPPF with $4 \times 4 \text{ cm}^2$ (b)

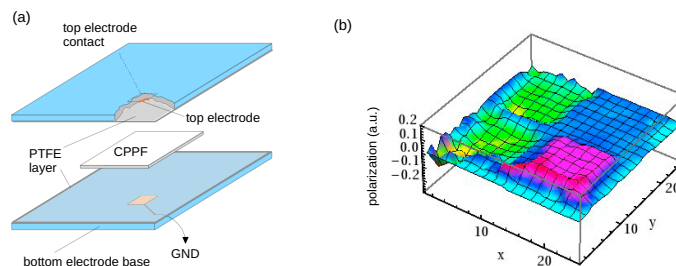


Figure 5: Contact electrode poling system for CPPF polarization (a). Bipolar contact-poled CPPF with $4 \times 4 \text{ cm}^2$ (b)

work, reproducibility is still a concern. Parameters like humidity, ion concentration and air-temperature are crucial factors which have strong influence on corona discharge polarization. More polarization experiments in a controlled atmosphere are necessary to increase reproducibility of patterned corona poling.

A well working alternative to corona poling is polarization with surface electrodes as shown in Fig. 5(a). The electrodes have to be laminated with a thin layer of polytetrafluoroethylene (PTFE) which serves as a charge trapping layer to quench possible local dielectric breakdown events of the CPPF at high field strength. Similar to the corona arrangement contact polarization too requires an exact match up of the top- and the grounded base-electrodes. Other nearby base-electrodes which are either floating or grounded will cause strong fringing fields and a significant degradation of the lateral resolution between adjacent areas of opposite polarization. The polarization pattern of a sample poled with surface electrodes is presented in Fig. 5(b). Polarization has been successively performed with a single set of top- and ground-electrodes, both covered with $25 \mu\text{m}$ thin PTFE layer. The applied poling voltage was 12 kV. This simple poling technique shows a good reproducibility and can thus be used to prepare heteropolar CPPFs for the fabrication of ultrathin keyboards and tactile sensors.

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